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ELECTROACTIVE ELASTOMERIC STRUCTURES (EAES) FOR HYDROACOUSTIC APPLICATIONS

R&D STATUS REPORT

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GENERAL ATOMICS

R&D Status Report

Smart Materials and Structures
Electroactive Elastomeric Structure (EAES) For Hydroacoustic Applications

ARPA Order No.:	BAA-94-17	**Program Code No.:**	Not Applicable
Contractor:	General Atomics	**Contract Amount:**	$739,177.00
Contract No.:	N00014-94-C-0264		
Effective Date of Contract:	29 September 1994		
Expiration Date of Contract:	30 September 1996		
Principal Investigator:	Dr. Terry D. Gulden		
Telephone No.:	(619) 455-2893		
Short Title of Work:	Electroactive Elastomeric Structure (EAES)		
Reporting Period:	1 April 1996 through 30 June 1996		

Description of Progress

The emphasis in this reporting period has been on test sample fabrication, characterization and testing in the NUWC Water Tunnel facility, supplemented by laboratory testing to provide basic understanding of the observed behavior in the Water Tunnel.

Characterization Studies of EAES Materials - After each test article was investigated at NUWC, the elastomer surface was examined at 10X, and often in addition, using a stereomicroscope to delineate evidence of material degradation. Photomicrographs were taken of distinguishable features such as; arc-to-water tears, microcracking in the cover layer elastomer, and rust particle deposition. This information was useful in explaining observed change in operational performance or the failure mode.

Composition Analyses - Characterization continued of the ER particles (Reslinol 815). Reslinol 815 particle types are incorporated in the ER elastomer zone of the EAES test articles tested at NUWC. The findings are presented in Table 1. In this reporting, the residual water content of two particles types was determined successfully by a gas chromatography method. Both water and lithium concentration are the composition parameters of highest importance for the electrorheological performance of Reslinol 815 particles.

Table 1

Composition Analyses of Reslinol 815[A] ER Particles

GA Code #	Method of Particle Sizing	Method of Chemical Analysis	Elements Detected/Measured						
			H_2O wt. %	Li Additive wt. %	Trace Elements[B]; ppm by weight				
					Al	Ca	Mg	Si	Na
RES 815F-VLC 50-396	Ball Milling	Emission Spectrographic		> 0.1	10-30	10-30	≤ 0.3	1-3	50-100
		Ion Coupled Plasma		3.3 ± 0.1					
		Gas Chromatography	1.4						
RES 815F-LC10-396	Jet-Milling	Emission Spectrographic		> 0.1	10-30	30-50	1-3	1-3	100-300
		Ion Coupled Plasma		3.1 ± 0.1					
		Gas Chromatography	3.1						

(A) Produced by ERFD. A phenol/formaldehyde polymer (#815) made with additives of LiOH and water.

(B) Non polymer specific. Any other trace impurities were not detectable to the sensitivity limits of emission spectroscopy, for most elements, ≤ 3 ppm.

Using excised samples carved from a test article (11296-3-2N&4N) evaluated in the water tunnel at NUWC, an attempt was made to determine whether the clear silicone elastomer which covered (to provide electrical isolation) the ER elastomer zone contained any contamination species (e.g. Fe, absorbed from the tap water medium). These elastomer samples were analyzed by the Emission Spectrographic method (ESA). None of the samples (including as-processed control samples) exhibited iron concentration. The ESA method has a 3 ppm detection sensitivity level.

Water Tunnel Tests - All test articles which have been tested to date at the New London Quiet Water Tunnel are listed in Table 2. During this reporting period, the last two of the listed articles were designed, constructed and tested. The table briefly summarizes the configuration of the test articles and the test results. Further test detail is provided in the following paragraphs.

TABLE 2

WATER TUNNEL TEST STRUCTURES

ARTICLE	CONFIGURATION	TEST RESULTS
1	No Grids	• Good Hydrophone Signals • Stable at High Flow Speeds
2	• Two Grid-Glued to Frame • Gold Scrim Electrodes • High Activity ER Fluid	• Good Hydrophone Signals • Gold Scrim Heating
3	• Two Grid Glued to Frame • Nickel Screen Electrodes • High Activity ER Fluid	• Grid Sag Leading to Thermal Runaway
4	• Two Grid Glued to Foam Spacer • Nickel Screen Electrodes • Low Activity ER Fluid	• Shorted at 9 kV to Water • No Acoustic Effect
5	• Two Grid - Floating on Threads • Nickel Screen Electrodes • Low Activity ER Fluid	• Some Acoustic Effect (6 kV) • Shorted Across Grids-After 1 Week in Water • Surface Micro - Cracks
6	• Two Grid Glued to Honeycomb • Nickel Screen Electrodes • Low Activity ER Fluid	• No Acoustic Effect • Shorted to Water
7	• Two Grid Glued to Foam Spacer with Holes • Nickel Screen Electrodes • Low Activity ER Fluid	• Unstable Surface - Tear • Surface Micro - Cracks
8 and 9	• Three Grid Floating on Threads • Nickel Screen Electrodes • Low Activity ER Fluid	• Stable Flow Performance • Some Acoustic Effects • Good Electrical Integrity
10	• Two Grid - Flow-Wise Wires • 10 MIL Wires on 40 MIL Centers • High Activity ER Fluid	• Stable Flow Performance • No Acoustic Effects • Good Electrical Integrity
11	• Two Grid - Annular Rings • E-Field Rotated 90^0 • High Activity ER Fluid	• Stable Flow Performance • E-Field Limited to 2 KV/MM - Stray Fields Interacted with Hydrophones • No Acoustic Effects
12	• Two Grid - Parallel Wires - Flow Direction • E-Field Rotated 70^0 • High Activity ER Fluid	• Stable Flow Performance • No Acoustic Effects • Shorted to Water at High Voltage

The first ten test articles listed in the table seemed to indicate low efficiency conversion of compression waves into shear waves resulting in low signal attenuation. To combat this performance short-fall, two new test articles were designed, fabricated and tested. The design concepts are centered on rotating the electric field by 90° to eliminate the need for wave conversion. In these tests, the surface disturbances were normal to the applied electric field. Test articles 11 and 12 were machined into a single base unit. The first test configuration consists of a cylindrical annulus with ring electrodes positioned on the wall faces to provide for a radial electric field. The annular region which was 5 mm across, was centered directly over a pair of hydrophones. The second structure was a simple rectangular depression which accommodated a two wire grid structure with a spacing of 2.6 mm inclined to the flow plane by approximately 20 degrees. A single hydrophone was mounted directly beneath the wire grids. Each of the configurations was loaded with a high activity EAES material with a 3 mm layer of clear 20/80 silicone top coat above to insulate the grid structures from the conducting water of the water tunnel. The completed test articles were packaged and shipped to the New London facility for testing.

The annular ring test article was first tested at a flow speed of 10 feet/second with applied voltages ranging from 0 to 10 kV/mm. Attempts to increase the voltage to higher levels caused an interaction with the piezoelectric elements of the hydrophones. Stray fields from the annular electrodes are suspected as the cause. This article was also tested (at the reduced voltage levels) at flow speeds up to 30 feet/second. No acoustic effects were noted at the highest applied field at any flow speed. The second test article which consisted of a wire grid structure did support higher voltages (up to 3 kV/mm) but also failed to provide any acoustic attenuation. These results seem to indicate that compression wave conversion to shear waves is not necessarily the cause of the performance short-fall.

Failure to effect the acoustic signal in any way is difficult to understand based on material test results that show relatively large variations in the complex modulus of the EASE material with variable applied voltage. The material should demonstrate either an attenuation or amplification of the hydrophone signal depending on the relative dominance of the loss or storage modulus variation. Grid structure configurations, active EAES volume fractions and field orientations have all been varied without success. Two other somewhat related variables can be considered as the cause for failure to observe a measurable effect. Both of these are related to the magnitude of the surface disturbance and/or the magnitude of its attenuation through the elastomer. Because the water tunnel uses relatively conducting water, an extra layer of non-active elastomer had to be added to the surface of most test articles as electrical insulation. In the case of the three grid structures, the extra layer was an EAES material with a grounded screen grid at the water surface. Any of these configurations effectively doubles the thickness of the test article allowing for considerable attenuation of the surface disturbance resulting from the turbulent flow conditions. In addition, the magnitude of the surface disturbance has been estimated to be quite small (on

the order of 10 to 20 microns). Either of these conditions (disturbance magnitude or signal attenuation) might impact the observed magnitude of the ER effect, and result in the observed absence of a measurable effect.

Controlled Compression Pressure Oscillation Testing - Using a vibrating actuator capable of exciting the surface of test articles with variable amplitude and frequency, both of the cited conditions can be evaluated. The resulting surface disturbance while not representative of flow conditions is adequate for the intended evaluation. A series of this type of pressure oscillation tests has been conducted at GA. Two water tunnel configurations were tested along with a new very thin two grid article which was constructed without a surface insulating layer of elastomer. The results of these tests are presented in the following paragraphs.

To investigate an EAES elastomer design of considerably smaller thickness, one of the present test articles was modified. Electrode screens were oriented parallel, with only 0.04 in. (1 mm) separation, and positioned over the hydrophone locations of the central region of the standard 2x7 in. recessed opening in an acrylic plate. An ER medium of high activity, as used in many of the flow tests performed to date, was used as the ER elastomer medium between and over the electrode screens. A relatively thin zone of the standard clear firm silicone elastomer was then poured as the top protective layer. A total elastomer thickness of only 0.067 in. (1.7 mm) was achieved in contrast to the standard 0.25 in. (6.4 mm) elastomer thickness of most test articles evaluated at NUWC and a more recent one of 0.48 in. (12.2 mm) thickness.

To accomplish a dynamic test on EAES test articles tested previously in the quiet water tunnel test at NUWC, the test system apparatus developed at GA for the measurement of shear moduli G' and G" was modified. The test apparatus was then used in conjunction with preamplifier and amplifier instrumentation provided by NUWC to measure compression pressure signals received by an underlying hydrophone. Design and fabrication was conducted to provide fixturing to enable positioning and clamping the plexiglass framework of the test article beneath a polymer (Delrin) pressure-foot (0.25 in. dia. rod with a tip radius of 0.5 in.) affixed to a vibration generator. Oscillation of the vertically oriented pressure-foot was perpendicular to the surface of the EAES surface. The test procedure incorporated an initial elastic depression of the pressure-foot to controlled depths of between 0.002 in. and 0.006 in. to establish firm contact. Then, for a set frequency value (5, 20, 100 and 200 Hz were chosen), the oscillation provided by the vibration generator was increased from a pre-set of $\pm$ 0.001 in. controlled motion to a value of interest ($\pm$ 0.002, $\pm$ 0.003 and $\pm$ 0.004 in. were selected for investigation). The precision of control was equal to $\pm$ 0.0001 in. The hydrophone signal was monitored and recorded using an oscilloscope (Yokogawa, Model DL 1540). From print-out recordings, amplitudes of the hydrophone signal were measured and recorded in tabular form. To assess the change in hydrophone signal when the test article zone of ER elastomer was stiffened by application of an electric field between the embedded electrodes, graphical presentations were prepared of the output as a function of

electric field for each frequency and depth of oscillation as shown in Figures 1 and 2. To examine the influence of combined parameters, Figure 3 was prepared.

Of particular importance was the finding shown in the bottom two curve sets for an oscillatory motion of ± 0.002 in. The hydrophone signal exhibited by the 1.7 mm thick elastomer test specimen (1 mm between electrodes) was responsive to changes in applied electric field and in oscillatory frequency of the compressive pressure pulse. For the considerably thicker (12.2 mm) test specimen the hydrophone exhibited a much lower signal and was not responsive to change in oscillatory frequency on the pressure-foot nor to the energized ER elastomer zone. The interpretation of this response is a high level of absorption by the thick elastomer.

SCHEDULE STATUS

A Gannt chart for the program is attached as Figure 4. The experimental portion of the program is now essentially complete. The principal task remaining is preparation of the Final Report.

ERRATA

Figure 1 was inadvertently omitted from the last R&D Status Report. It is included here as Figure 5.

PROBLEMS ENCOUNTERED AND/OR ANTICIPATED

The experimental results show that the EAES concept does not have sufficient response to be effective as a wavenumber filter. The small excitations due to flow noise, along with the inherent signal attenuation of the elastomeric material itself, result in too small an electroactive effect to be useful in this application. The experimental results show that the EAES concept is more suited to applications where the amplitude of excitation are larger.

ACTION REQUIRED BY THE GOVERNMENT

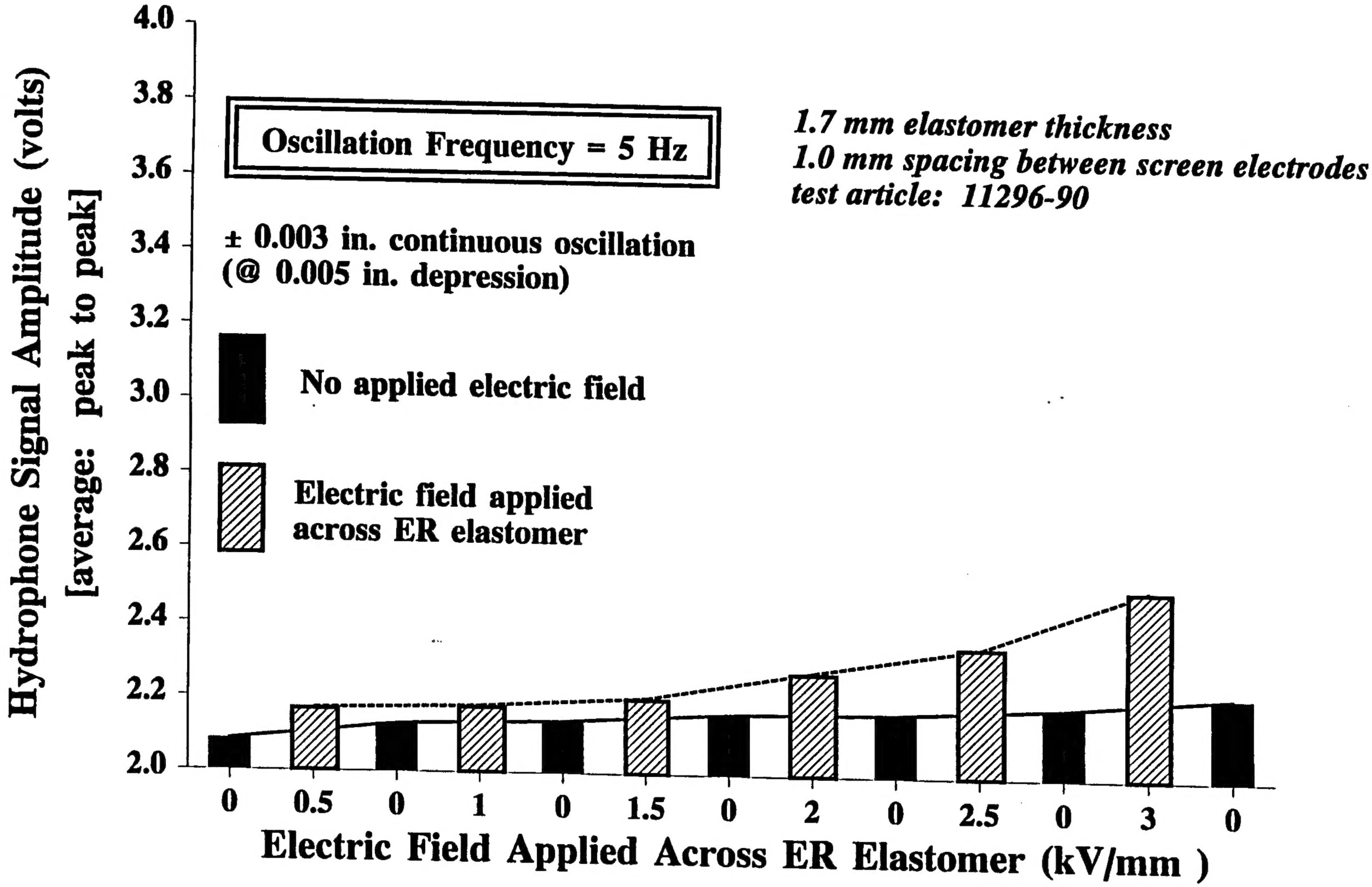
A "no-cost" extension to the end of the calendar year will be requested to allow sufficient time to complete preparation, review and publication of the Final Report.

FISCAL STATUS (as of June 31, 1996)

1. Amount currently provided on contract	$ 739,177.00
2. Expenditures and commitments to date	$ 612,019.00
3. Funds required to complete work	$ 127,158.00

Figure 1

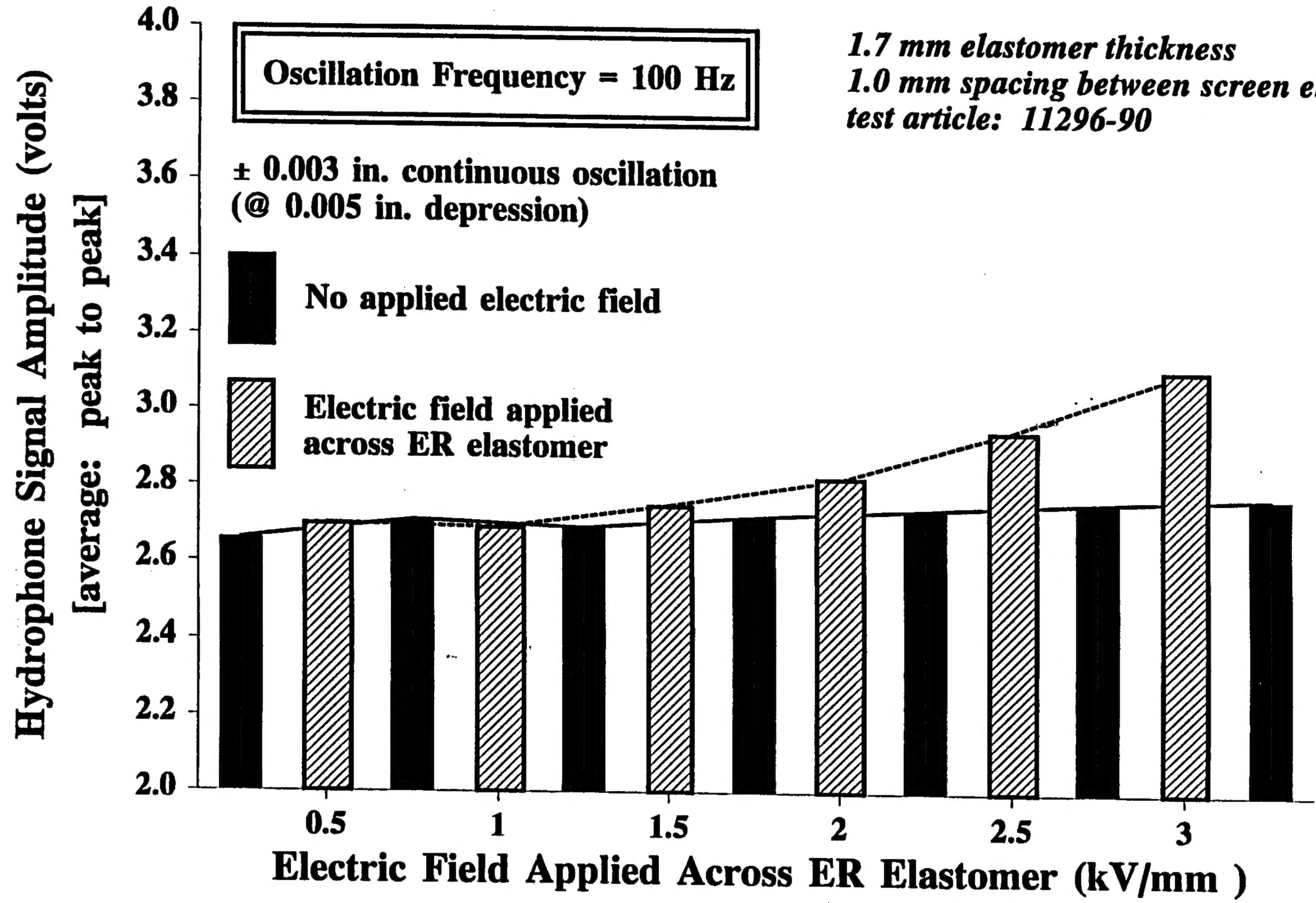
Influence of Electric Field Applied Across Electroactive Elastomer on Compressive Pressure Pulse Transmitted to an Underlying Hydrophone



Response signal increases as the ER elastomer becomes stiffer.

Figure 2

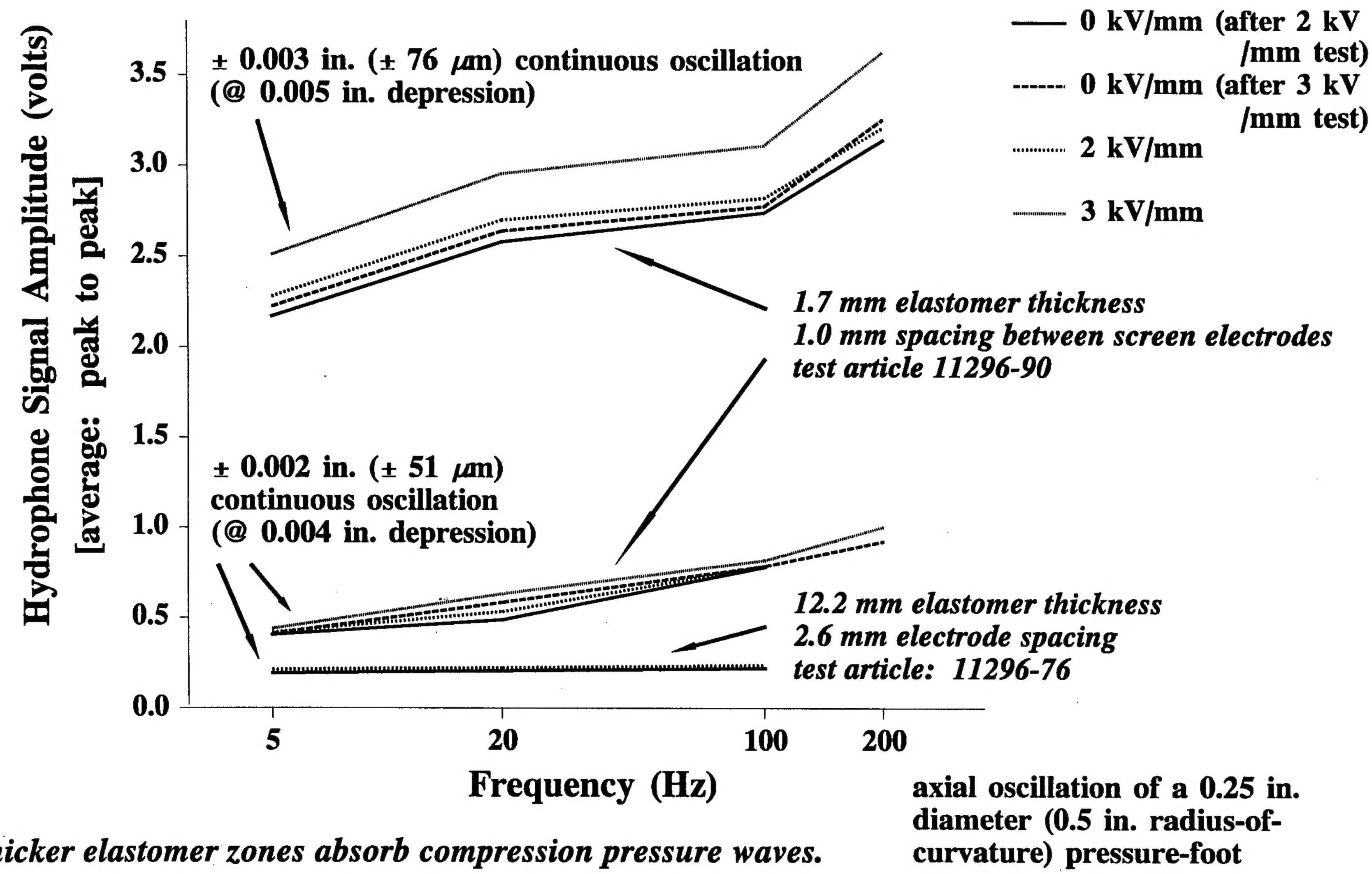
Influence of Electric Field Applied Across Electroactive Elastomer on Compressive Pressure Pulse Transmitted to an Underlying Hydrophone



Response signal increases as the ER elastomer becomes stiffer.

Figure 3

Hydrophone Response to Compressive Pressure Oscillation on Surface of Elastomer Test Specimens which Include an Electroactive Elastomer Zone



Thicker elastomer zones absorb compression pressure waves.

Figure 4: Electroactive Elastomeric Structures (EAES) Program-Schedule and Milestones

ID	Task Name
1	**1.0 Hydrodynamic/Acoustic Modeling**
2	1.1 Performance Modeling
3	*1.1 Complete Initial Performance Model*
4	*1-2 Complete Second Performance Model Iteration*
5	*1-3 Complete Final Performance Model*
6	1.2 Model Evaluation
7	*1-4 Verification of Initial Model*
8	*1-5 Verification of Second Model Iteration*
9	*1-6 Verification of Final Model*
10	**2.0 Test Definition and Planning**
11	2.1 Develop Test Specifications
12	*2-1 Specification for initial test series*
13	*2-2 Specification for second test series*
14	*2-3 Specification for final test series*
15	**3.0 EAES Material Structures Development**
16	3.1 Composition Variation/Optimize
17	*3-1 Specify material for initial test series*
18	*3-2 Speciify material for second test series*
19	*3-3 Specify material for final test series*
20	3.2 Qualification Testing
21	*3-4 Complete initial qualification test series*
22	*3-5 Complete second qualification test series*
23	*3-6 Complete final qualification test series*
24	3.3 Conducting Elastomer Variation
25	*3-7 Specify conducting elastomer for first test series*
26	*3-8 Specify conducting elastomer for second test series*
27	*3-9 Specify conducting elastomer for final test series*
28	**4.0 Active Control Specification and Development**
29	4.1 Control Software Development
30	*4-1 Complete control software for initial test series*
31	*4-2 Complete control software for second test series*
32	*4-3 Complete control software for final test series*
33	4.2 Hardware and Sensor Integration
34	*4-4 Complete control software and sensor specification*
35	*4-5 Complete control software and sensor specification*
36	*4-6 Complete control software and sensor specification*
37	**5.0 Test Article Design and Fabrication**
38	5.1 Hydroacoustic Panels
39	*5-1 Complete fabrication of hydroacoustic panels*
40	*5-2 Complete fabrication of hydroacoustic panels*
41	*5-3 Complete fabrication of hydroacoustic panels*
42	5.2 Anechoic Discs
43	*5-4 Complete fabrication of anechoic discs*
44	*5-5 Complete fabrication of anechoic discs*
45	*5-6 Complete fabrication of anechoic discs*
46	**6.0 Forming and Fabrication Procedures Development**
47	6.1 Develop Molding and Bonding Techniques
48	*6-1 Deliver stability test samples to NUWC*
49	*6-2 Complete development of molding and bonding techniq*
50	*6-3 Complete development of molding and bonding techniq*
51	*6-4 Complete development of molding and bonding techniq*
52	**7.0 Performance Testing**
53	7.1 Setup and Operations
54	*7-1 Complete initial performance test series*
55	*7-2 Complete second performance test series*
56	*7-3 Complete final performance test series*
57	7.2 Data Reduction and Analysis
58	*7-4 Complete data analysis for initial test series*
59	*7-5 Complete data analysis for second test series*
60	*7-6 Complete data analysis for final test series*
61	**8.0 Management and Reporting**
62	8.1 Quarterly Reports
63	*8-1 Submit quarterly report*
64	*8-2 Submit quarterly report*
65	*8-3 Submit quarterly report*
66	*8-4 Submit quarterly report*
67	*8-5 Submit quarterly report*
68	*8-6 Submit quarterly report*
69	*8-7 Submit quarterly report*
70	8.2 Program Reviews
71	*8-8 Program review meeting*
72	*8-9 Program review meeting*
73	*8-10 Program review meeting*
74	8.3 Final Report
75	8.11 Complete Final Report

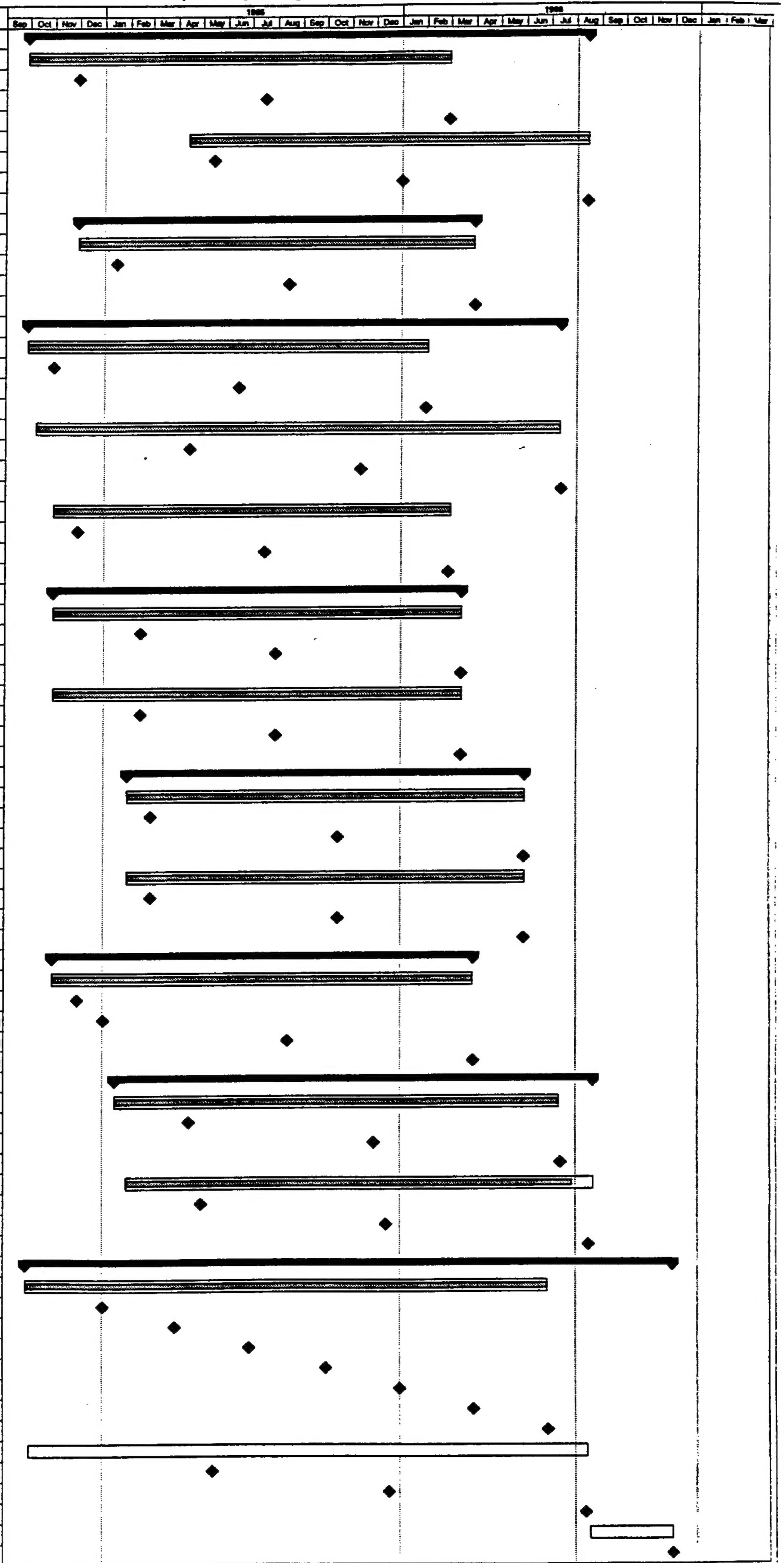
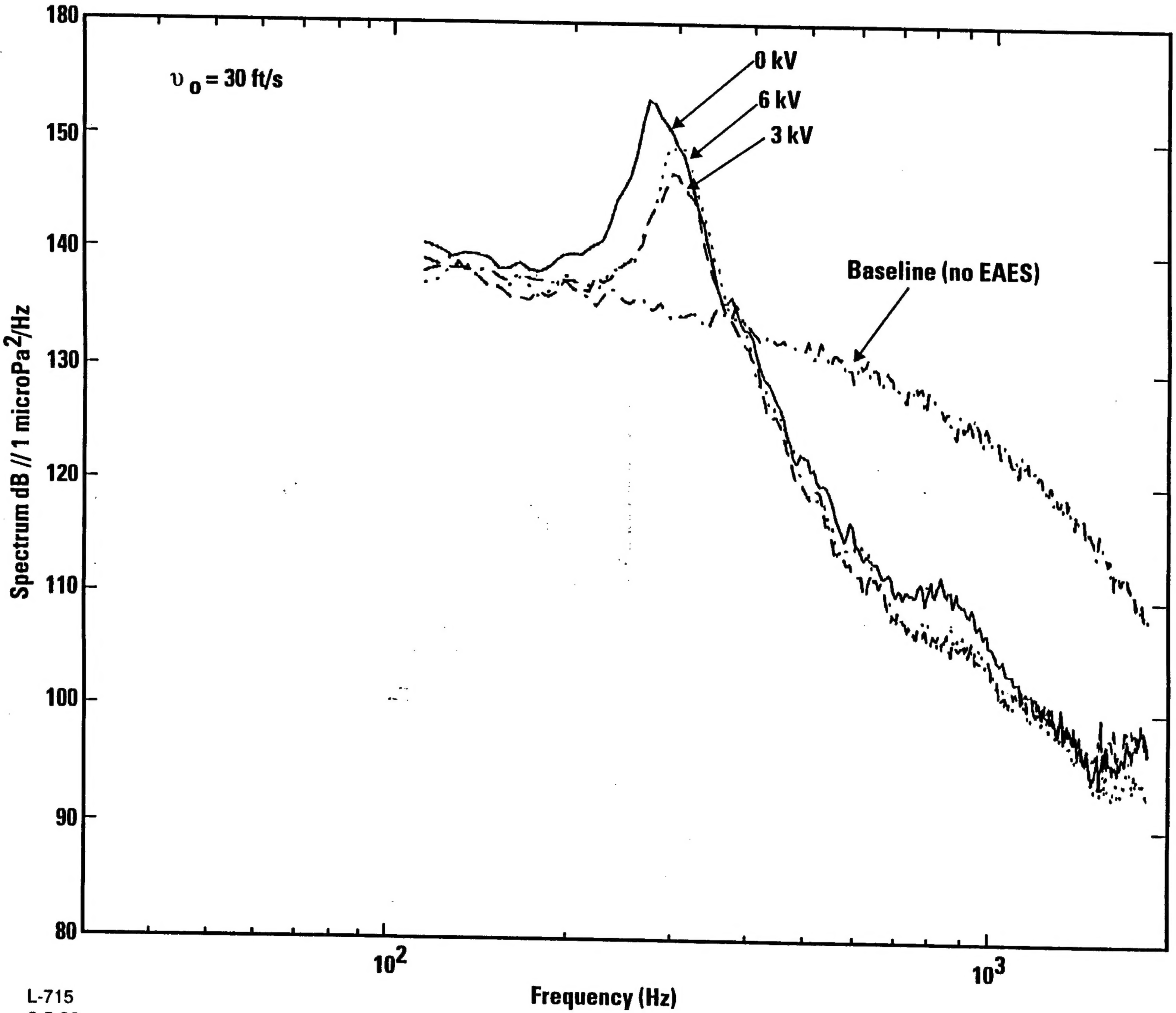


Figure 5 Responsive Curve for Test Article 5 in the NUWC Quiet Water Tunnel



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